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# The accuracy of different generation intraocular lens power formulas in eyes with axial length less than 22 millimeter

Intraocular lens power in short eyes

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**Abstract**

Aim: In this study, we aimed to investigate the accurate formulas for eyes with axial length (AL) less than 22 millimeters among usually used six intraocular lens (IOL) calculation formulas.

Material and Methods: This retrospective study included 137 eyes with short ALs below 22 mm of 122 patients who underwent phacoemulsification surgery with the same type of IOL implantation. The biometric values of the patients were obtained using optical low coherence reflectometry (OLCR) for six formulas involving Hoffer Q, SRK-T, Haigis, Barett Universal II, Holladay 2 and Hill-RBF. All patients in the postoperative period had the best-corrected visual acuity level equal to or higher than 20/40. While comparing the accuracy of these six IOL calculation formulas, the mean absolute error (MAE), and the median absolute error (MedAE) values were taken into account.

Results: The MAE values for Hoffer Q, SRK-T, Haigis, Holladay 2, Hill-RBF and Barrett Universal II formulas were 0.390, 0.390, 0.324, 0.327, 0.331 and 0.208, respectively. Also the rank of MedAE values for the mentioned formulas was 0.245, 0.310, 0.310, 0.250, 0.255 and 0.190. The lowest MAE and MedAE values were found in the Barrett Universal II formula, whereas the highest one was in the SRK/T formula with a statistical significance ($p<0.001$). After Bonferroni correction, there was no statistically significant difference between the Barrett Universal II formula and the other formulas except for SRK/T ($p>0.01$). Three patients (2.5%) were in the ±0.75 D range, 15 patients (12.3%) were in the ±0.50 D, and the remaining 104 (85.2%) patients were during the ±0.25 D at the first-month follow-up.

Discussion: Although Barrett Universal II appears to be the most accurate IOL calculation formula, third, fourth and other newer generation formulas have also good predictive value for accurate estimation of IOL power in short eyes.

**Keywords**

Cataract; Intraocular lens; Short eye

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## Introduction

The lens extraction and IOL implantation surgery is performed either to remove the lens opacification or for the purpose of refractive correction in subjects who are not suitable for keratorefractive approach. Combined advances in the surgical technique and IOL design, such as small incision cataract surgery with implantation of aspheric monofocal, toric or multifocal IOL, have increased refractive outcomes for quality of vision. In uncomplicated lenticular surgery, two main factors can affect the postoperative good visual acuity. The first one is the surgical factor that may involve, for example, the site and width of the corneal incision, and the second factor is the detection of the postoperative accurate IOL power. Although the first factor partially depends on the experience of the surgeon, the second one seems to be more predictable if the proper IOL power is selected for the surgery.

The main factors determining an accurate calculation of IOL strength are accurate measurement of axial length (AL), corneal optical power, namely keratometry (K), and assessment of postoperative effective lens position (ELP). Among these determinants, AL measurement error is the most common cause of incorrect calculation of the IOL force. [1,2]. There are no major problems when calculating the IOL power for normal eyes with AL between 22-26 mm. However, for those outside of this range, known as short (AL≤22 mm) and long eyes (AL≥26mm), accurate lens determination may occasionally be problematic while using the first (Binkhorst), the second (SRK-II), the third (Holladay 1, SRK-T and Hoffer Q) generation IOL calculation formulas, incorporating mainly AL and K.

It has been noted that an important reason for incorrectly calculating IOL power for short and long eyes is associated with an incorrect prognosis of postoperative ELP [3]. Therefore, apart from only the use of AL and K, additional parameters, such as measurement of anterior chamber depth (ACD), lens thickness (LT), lens factor (LF), and white-to-white (WTW) distance, were included in the fourth generation (Haigis, Holladay 2 and Olsen) and new generation (Barrett Universal II, Hill-RBF) formulas to assess postoperative ELP [4,5]. Although several studies have shown insignificant difference between Haigis, Holladay 2, Hoffer Q, Holladay 1, SRK/T and SRK II for calculating the accurate IOL power in short eyes [6-8], a study by Macleran et al., showed that Haigis is more accurate than Hoffer Q [9], while Gavin et al. suggested that Hoffer Q yielded better results than SRK-T [10].

Aristodemou et al. in their comprehensive study suggested that Hoffer Q has a good performance in IOL calculation for ALs from 20 to 20.99 mm, and along with Holladay 1, from 21 to 21.49 mm [11]. However, there is little research in the literature on the effectiveness of new generation IOL calculation formulas, especially Barrett Universal II, for the short eyes [3,12].

In the present study, it was aimed to compare the effectiveness of IOL calculation formulas between third and fourth generation formulas such as SRK-T, Hoffer Q, Holladay 2, Haigis, and new generation formulas such as Barret Universal II, and Hill-RBF in short eyes.

## Material and Methods

This retrospective clinical study was carried out by examining the medical records of the patients who experienced a cataract surgery between 2014 and 2018. The institutional review board of Canakkale University approved the study protocol (desicion date: 02.01.2019, desicion number: 2019-11). This study included patients with AL lower than 22 millimeters who underwent uneventful cataract surgery with the same type of monofocal IOL implantation (Acriva UD 613®, VSY Biotechnology, Turkey). Other inclusion criteria for this study were the availability of the measurement of IOL power obtained using OLCR alone (Lenstar LS-900, Haag-Streit AG, Koeniz, Switzerland) and the determination of the postoperative best-corrected visual acuity level ≥20/40 in the first-month visit. Patients with a history of traumatic cataract, previous refractive surgery, and retinal detachment, as well as the ones with keratoconus, corneal scarring, corneal dystrophy, macular edema, complicated cataract surgery, and also the patients who had not come to first-month visit, were excluded from the present study.

All patients were subjected to detailed ophthalmic examination with a slit-lamp biomicroscopy during the pre-and postoperative period. The AL and K values and ACD measurements were obtained by OLCR. The phacoemulsification surgery was performed with a 2.8 mm clear-corneal incision, 5.0-5.5 mm capsulorhexis diameter and IOL implanted into the bag. None of the corneal incisions required suture. The characteristics of the implanted IOL were as follows: mono-focal lens with a plate haptic design, the optical diameter was 6.0 mm, the total diameter was 13.0 mm, the haptic-optic angle was 0 degree, the refractive index was 1.46. In previous studies, since all formulas were not registered in one device, the calculation of new generation formulas was made from the websites. The optimization values of the Acriva UD 613 can be also found in ULIB website [(A constant=118.0), (Haigis a0=0.95, a1=0.40, a2=0.10), (Hoffer Q pACD=5.19), Holladay 1 (sf=1.43), and (A constant for SRK/T= 118.4)]. The Lenstar LS-900 contains the software for the IOL calculation formulas that were included in this study and all formulas were pre-installed on this biometer. Therefore, no additional calculation from the websites was used in the current study.

A total of six formulas (Holladay 2, Hoffer Q, SRK/T, Haigis and the Hill-RBF, an artificial intelligence based radial basis function method) were compared with Barett Universal II. In terms of the number of variables in the IOL calculation, formulas are as follows: Hoffer Q and SRK/T formulas have 2 variables [K and AL values], Haigis formula has 3 variables [ACD in addition to K and AL]. The Barrett Universal II formula has 5 variables [AL, K, ACD, WTW, and LT]. Holladay 2 formula has 7 parameters [K, AL, ACD, LT, WTW, preoperative refraction and patient age].

To reduce the problems owing to IOL constant optimization, similar to the study by Carifi et al. [7], only subjects with the same type of monofocal IOL (Acriva UD 613®, VSY Biotechnology, Turkey) were included in this study.

The refractive prediction error, namely the MAE and also the MedAE values, were calculated by subtracting the postoperative spherical equivalent (SE) value from the estimated error value for each formula. The MAE values were used as the main data for the comparison of the accuracy of formulas. For each formula, the benchmarks as ± 0.25 D, ± 0.50 D, and ± 0.75 D were calculated. The subjective refraction was performed at the first month visit. The SE value was calculated by adding half of the cylindrical power to the spherical power.

***Statistical Analysis***

Statistical analysis was performed using the Statistical Package for the Social Sciences and Social (Version 21.0, SPSS, Inc.). Friedman's test was applied for the comparison among the groups. The Bonferroni correction was implemented for multiple comparisons, and the statistical significance was accepted as a p-value of less than 0.01 after Bonferroni correction.

**Results**

A total of 137 eyes of 122 patients were included in this study. Fifteen patients were operated on two eyes and a randomly selected eye was included in the study. The mean age of the patients was 66.5 ± 5.7 (min: 55, max: 81) years. Forty-three patients were female (35%) and 79 were male (65%). The mean AL was 21.38 ± 0.53 (min: 20.03, max: 21.98, median: 21.59) mm. The mean IOL power was 26.4 ± 2.2 (min: 23.5, max: 32.5) D. The data related to the refractive values are given in Table 1. The MAE values were 0.390 for Hoffer Q, 0.390 for SRK-T, 0.324 for Haigis, 0.327 for Holladay 2, 0.331 for Hill-RBF, and 0.208 for Barrett Universal II. The ranks of MedAE values for the mentioned formulas were 0.245, 0.310, 0.310, 0.250, 0.255 and 0.190, respectively. The lowest MAE and MedAE values were found in Barrett Universal II, while the highest value was in the SRK/T formula. All MAE and MedAE values are shown as minimum, maximum and standard deviations in Table 2. Although there was a statistically significant difference between the Barret Universal II and SRK/T formula (p<0.001) , no statistically significant difference was determined between the Barrett Universal II and the other formulas after Bonferroni correction in terms of MAE value (p>0.01). Also, a statistically insignificant difference was found between other formulas other than the Barrett Universal II formula (p>0.01).

While the mean and the median preoperative SE values were +4.47 D and +4.38 D, respectively, their postoperative values were -0.16 D and -0.25 D, respectively. Three patients (2.5%) were in +/- 0.75 D range, 15 patients (12.3%) in +/- 0.50 D, and the remaining 104 patients (85.2%) were in +/- 0.25 D in the first month visit. All patients were in the benchmark of 1.00 D suggested by Gale et al. [13].

**Discussion**

Unlike those with long and normal AL, calculating IOL power can sometimes be difficult in patients with short eyes. This condition is mostly attributed to an incorrect estimation of postoperative effective lens position (ELP) that is defined as the distance between the secondary principal plane of the cornea and the principle of the IOL [14]. The minimal deviation in the ELP is said to cause a considerable error in postoperative refraction, particularly in patients with short eyes, likely due to the implantation of thicker IOLs [9]. A potential risk of myopia may occur if the IOL is even minimally more anteriorly located than the expected, while hyperopic shift can emerge in case of its posterior location. Olsen et al. have put in order the important sources of error for IOL power calculation, such as incorrect measurements of AL (%54), ACD(38%), and corneal power (8%) [4]. However, Olsen reported in another study that most of the faults in IOL power calculations might be related to the underestimation of ACD rather than AL [2]. An error of one millimeter in the ACD measurement results in approximately 1 D, 1.5 D, and 2.5 D postoperative refractive error in myopic, emmetropic, and hyperopic eyes, respectively [15]. In addition, each 0.1 mm error in the AL measurement results in a deviation in the optical plane of almost 0.27 D [2]. Hence, the correct assessment of postoperative ACD becomes as important as measurement of AL, especially in patients with short eyes.

The refractive surprises arising from the incorrect measurement of AL have been largely resolved using non-contact biometry devices such as OLCR. Taking into account the fact that measurement error in short eyes causes 5 times more refractive error than myopia [2], resolving AL measurement problems using non-contact biometry has improved the refractive outcomes, particularly in these subjects. Another important benefit of non-contact biometry is the ability to correctly measure ACD. Factors affecting the ELP are classified, firstly, as anatomic causes such as K value, AL, white-to-white distance, preoperative ACD, and lens thickness (LT), and secondly, as IOL related causes such as shape, length, elasticity, angle, and haptic material of the IOL. As it is known that members of third-generation formulas like SRK/T, Holladay I and Hoffer Q, respectively, use the constant A (its value differs depending on the manufacturer and type of the IOL, as well as its position

**Table 1.** The comparison of mean preoperative and postoperative refractive outcomes in terms of spherical equivalent

| | Preoperative | | | Postoperative | | |
|---|---|---|---|---|---|---|
| | SD | CD | SE | SD | CD | SE |
| Mean ±SD | -6.45 ± 2.7 | -0.42 ± 0.78 | -6.76 ± 2.75 | -0.27 ± 0.31 | -0.65 ± 0.66 | -0.51 ± 0.21 |
| Min-Max | -1.75 to-17.00 | -2.00 to +2.50 | -1.38 to-17.00 | -0.25 to-1.25 | -2.00 to 2.00 | 0.12 to -1.00 |

SD: Spherical diopter, SE: Spherical equivalent, CD: Cylindirical diopter,
Min: Minimum, Max: Maximum, SD: Standard Deviation

**Table 2.** The comparison of prediction values between all formulas

| | Hoffer Q | SRK-T | Haigis | Holladay2 | Hill-RBF | Barrett |
|---|---|---|---|---|---|---|
| MAE Mean±SD | 0.390 ±0.2 | 0.390 ± 0.3 | 0.324±0.2 | 0.327 ±0.3 | 0.331 ±0.3 | 0.208 ± 0.165 |
| Range | 0.00-1.87 | 0.01-2.14 | 0.00-1.18 | 0.00-2.09 | 0.01-2.21 | 0.00-0.92 |
| MedAE | 0.255 | 0.190 | 0.245 | 0.310 | 0.310 | 0.250 |

MAE: Mean absolute error, MedAE: Median of Absolute Error.

inside the eye), the surgeon factor (SF), and postoperative ACD for ELP assessment. However, unlike the third generation, fourth-generation formulas involving Haigis formula (a0, a1, a2 constants), Holladay II formula (AL, K, ACD, LT, W-to-w, preoperative refractive error, and age) and Olsen formula (AL, K, white-to-white, LT and ACD) use additional variables besides the measurement of preoperative ACD for strengthening the estimation of ELP.

Several studies can be found in the literature comparing the accuracy of IOL power calculation between the third, fourth and newer generation formulas (Barrrett Universal II, Hill-RBF) either in patients with various AL, or in patients with short eyes. According to these studies, almost all IOL calculation formulas have been suggested to obtain favorable refractive results in average ALs. However, some IOL power calculation formulas have become more preferable in patients with short AL because of their success in reducingrefractive surprises. Narvaez et al. have reported equal refractive results when comparing the efficacy of Hoffer Q, Holladay 1, Holladay 2 and SRK/T formulas for short, medium and long eyes [16]. Karabela et al. have obtained good outcomes for both short and long eyes by using the SRK/T formula [17]. In contrast to these studies, Aristodemou et al. have demonstrated the superiority of SRK/T and Hoffer Q in eyes with AL greater than 26 mm, and less than 21.5 mm, respectively, in their comprehensive study [11]. However, either the study by MacLaren et al. or the study by Wang et al. have found that the Haigis formula can yield more accurate postoperative refractive results than Hoffer Q, SRK/T and Holladay 1 for short eyes [9,18]. Although the Haigis formula also showed more accurate results than the Hoffer Q, SRK/T and SRK II for shorter eyes in a meta-analysis by Wang et al. [14], Roh et al. reported the insignificant difference between Haigis and Hoffer Q formulas [19]. Since Hoffer Q and Haigis formulas include preoperative ACD measurement, their increasedaccuracy for shorter eyes may be associated with the increased true estimation of ELP. Olsen has defined an equation containing preoperative ACD, preoperative LT and “C constant” for the precise prediction of postoperative IOL position [20]. On the other hand, a new generation formula that is a mathematical approach, Hill-RBF does not use vergence formula and ELP separately for IOL power calculation. This formula makes calculations using ACD, AL, K and a special software that is preinstalled in OLCR (Lenstar, Haag-Streit) device.

Although Gokce et al. have suggested similar results between Barrett Universal II, Haigis, Hill-RBF, Hoffer Q, Holladay 1, Holladay 2, and Olsen formulas in 86 patients with AL equal to or less than 22 mm, the highest MAE value was determined with the Haigis formula followed by the Olsen formula in their study [3]. In contrast to this study, besides the superiority of the Barrett Universal II formula over SRK/T, Hoffer Q and Hill-RBF formulas, there was also a slight difference in MAE values between some third, fourth and new generation formulas in short eyes in the current study. Since in the present study all formulas except SRK/T contain the ACD variable for IOL power calculation, the highest MAE value due to the SRK/T formula might have arisen from the decreased prediction of ELP. In the current study, the second highest MAE values, followed by the SRK/T formula, were detected in the Hoffer Q and Hill-RBF formulas. The reason for the higher MAE value in these formulas may be result of reduction in the prediction of ELP, because Hill-RBF uses ELP estimation separetely, and unlike Hoffer Q formula, fourth and newer generation formulas involve more variables to strengthen the precise prediction of ELP apart from using ACD, for example, Haigis formula contains a0, a1 and a2 constants.

Although in contrast to the present study, Kane et al. have revealed lower MAE value using the Hill-RBF formula compared to the Barrett Universal II formula in shorter eyes, which contradicts the result of the current study, none of the new generation formulas was shown to yield more accurate postoperative refractive outcome than the Barrett Universal II formula, or the best third generation formulas in the same study [8].

In the Olsen formula, two different softwares, OlsenStandalone, and OlsenOLCR have been suggested to give distinct outcomes [21]. In the present study, the Olsen formula could not be included in the comparison because of the lack of information about its version installed in the biometric device, namely, it was not known whether the software was OlsenStandalone, or OlsenOLCR, and it is considered as the major limitation of the present study.

### *Conclusion*

It is thought that despite the superiority of the Barrett Universal II formula in the estimation of accurate refractive outcome in shorter eyes, the other generation IOL power calculation formulas may also provide satisfactory results for these patients in case of unavailability of software of new generation formulas in the biometric device.

***Scientific Responsibility Statement***
*The authors declare that they are responsible for the article's scientific content including study design, data collection, analysis and interpretation, writing, some of the main line, or all of the preparation and scientific review of the contents and approval of the final version of the article.*

***Animal and human rights statement***
*All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. No animal or human studies were carried out by the authors for this article.*

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